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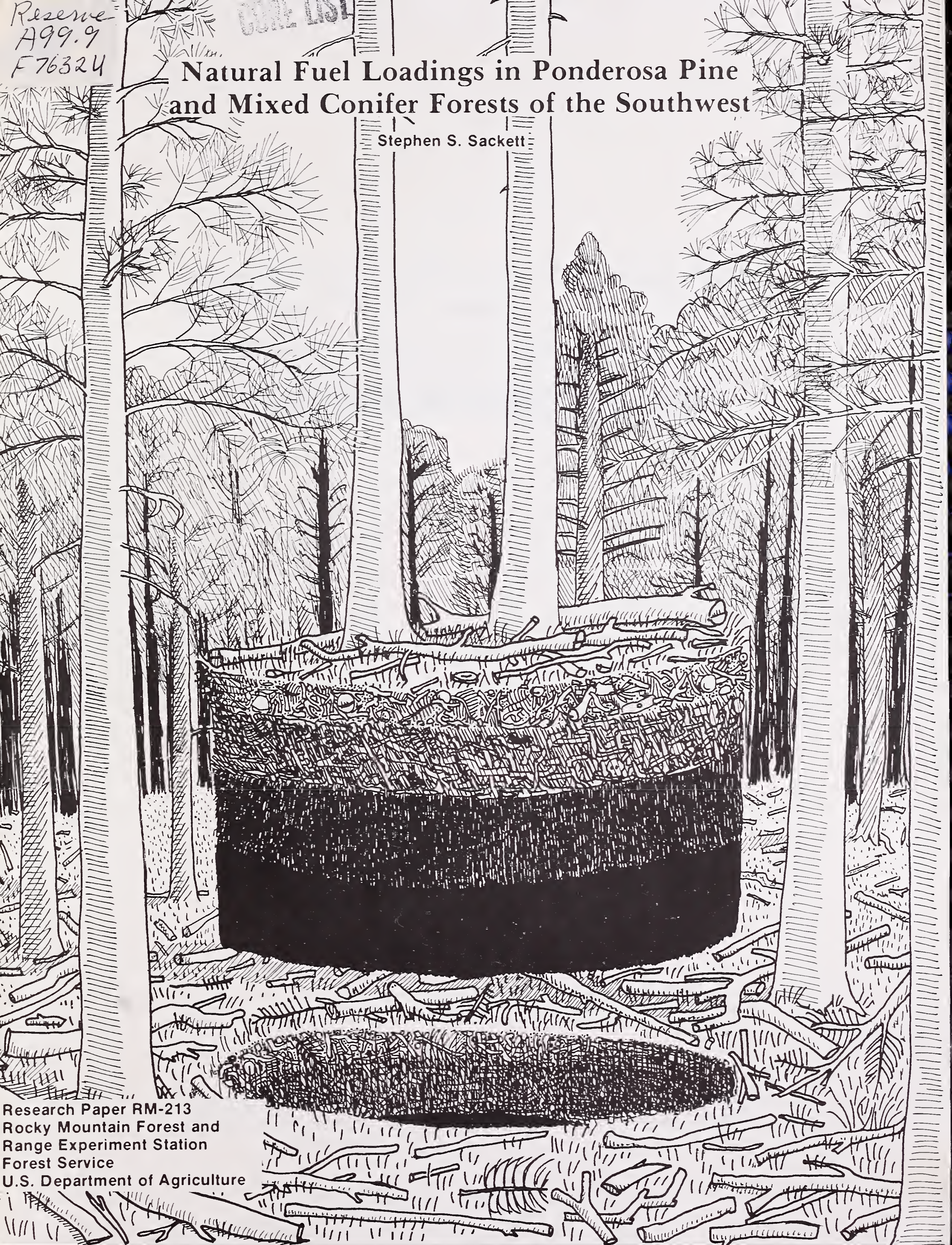
Natural Fuel Loadings in Ponderosa Pine and Mixed Conifer Forests of the Southwest

Stephen S. Sackett



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Abstract

Natural dead fuel loading in 62 undisturbed southwestern ponderosa pine stands averaged 21.9 tons per acre, 12.7 tons per acre ≤1-inch diameter. Sixteen mixed conifer stands averaged 44.1 tons per acre of dead fuel. Heavy humus loads contributed to loading of 22.2 tons per acre of fuel ≤1-inch diameter.

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Management Implications

No reliable method could be found to predict natural dead fuel loadings in ponderosa pine (common and scientific names in app. 1) and mixed conifer forests of the Southwest using basal area and/or a number of other independent stand variables. Variation within and between stands is too great to make fuel loading estimations practical. However, the study reported provides a better understanding of the existing wildland fuel situation.

Some wildland managers are concerned primarily with activity-generated fuel (slash), but natural fuel can be a problem in itself. Natural fuel loads can cause extreme fire behavior conditions during dry, windy weather experienced almost every fire season in the Southwest. Fires traveling through fine surface fuels common in southwestern ponderosa pine forests can produce fireline intensities and flame lengths great enough to seriously damage productive overstories. Flame lengths of the magnitude potentially available make crowning probable in typical southwestern ponderosa stands having large proportions of continuous, vertical ladder fuels in the form of stagnated (doghair) thickets. Two-thirds of the large fuel is rotten, punky, woody material adding to extreme fire behavior in the form of spotting and torching.

Although natural fuel loads in mixed conifer were found to be twice the weight of ponderosa pine, the seriousness of the condition is greatly reduced because mixed conifer grows in areas where critical fire weather is infrequent. One source of heavier loading is in the duff that can cause tedious mopup problems after a wildfire. Another is the large woody fuels that add to spotting and torching. Rapid surface fire spread in mixed conifer is not a serious threat because of the short, compact needles.

Even though an effective natural fuel estimator is not yet available for Southwest forest conditions, this paper points out the need for practicing fuel management in natural timber stands as well as in stands where activity-generated fuels are being created. In fact, fuel reduction in advance of fuel-generating activities will reduce the seriousness of the slash problems. Both fine surface fuels and large woody fuels create unique fire problems given a fire start. Both need to be dealt with in managing fuels. The fine surface fuels are managed to reduce rates of fire spread; resistance to control is modified by treating the large fuels.

Introduction

Accurate estimates of natural fuel loading are needed in a variety of situations, such as predicting fire behavior and damage; preattack planning; developing fuel management plans; assessing fire potential in and around residential developments in forests; and as an aid to silviculturists, landscape architects, wildlife biologists, and land use planners.

Such information is needed in Arizona, New Mexico, and Colorado for ponderosa pine (10.3 million acres according to Schubert 1974) and mixed conifer (2.5 million acres according to Jones 1974) forests, many in need of fuels management to eliminate excessive fuel loadings.

Literature

Byram (1959) developed a fire intensity formula involving the relationship between available fuel loading, heat content of the fuel, and rate of spread. The formula is expressed as:

$$I = Hwr$$

where

I = fire intensity (Btu/ft/s of fireline)
H = heat content of the fuel involved (Btu/lb)
w = weight of available fuel (lb/ft^2)
r = rate of spread (ft/s)

A number of fire effects can be related to fire intensity, including crown scorch and/or consumption of standing timber. In loblolly pine, for instance, fireline intensities greater than 1,000 Btu/ft/s can easily kill crop trees (Sackett 1972). Van Wagner (1973) did a similar study in Canada and established a relationship between fire intensity and scorch height in red, white, and jack pine stands.

Fuel loading estimates have been obtained in a number of ways. Slash loading can be predicted from information obtained in the timber sale survey (Brown et al. 1977, Wade 1969, Wendel 1960). Downed woody material can be inventoried using the planar intersect method to determine loading (Brown 1974). Forest floor weights, however, have been studied only to a limited extent in Arizona and with conditional success because of inherent variability. Ffolliott et al. (1968, 1976, 1977) and Aldon (1968) studied forest floor weights in conjunction with water retention on some Arizona watersheds. These works included prediction equations relating forest floor weight to stand basal area (Ffolliott et al. 1968, 1976, 1977) and age (Aldon 1968) but from very limited data. Brown (1970), while studying ponderosa pine fuels in Montana, found an average of 2,890 pounds per acre of litter (L layer) and as much as 23,400 pounds per acre of total forest floor material. Dieterich (1963) related basal area to fuel weight in comparatively homogeneous red pine plantations with relatively good success. Work by Brender et al. (1976) related fuel weight to age of stand and basal area in loblolly pine plantations. Additional work by McNab and Edwards (1976) predicts fuel loading of slash and longleaf pine by age of rough (time since last burn). From previous studies, basal area seems to be the best single predictor (Brender et al. 1976, Kiil 1968, Dieterich 1963).

Previous research indicates that large variations in fuel weight may be expected within any stand due to differences in stand density, age, site, species, previous activities, etc. Then too, "Southwest ponderosa pine occurs mainly as irregular, uneven-aged stands consisting of small even-aged groups." (Schubert 1974). This study sampled different combinations of "small even-aged groups" in an effort to determine fuel loading on a broad base—one on which management decisions must be made. That condition adds yet another source of variation.

This report confirms the inherent variability, with conclusions being based on a program of intensive sampling in a large number of ponderosa pine and mixed conifer stands in Arizona, New Mexico, and southern Colorado. Those working with treatment and manipulation of natural fuels should be aware of this variability.

Study Objectives

A study was begun in 1975 to determine fuel loadings in ponderosa pine and mixed conifer forests of the southwestern United States and to develop prediction equations for the estimate of those fuels.

Ponderosa pine and mixed conifer stands were selected in cooperation with various timber and fire management personnel for fuel loading studies on various public lands throughout Arizona, New Mexico, and southern Colorado. Mature stands selected represented the conditions on a particular forest or area. Further, the stands had not been disturbed by fire, disease, or insects, or any man-caused activity (e.g., logging or thinning) for at least 20 years. Stands undergoing or proposed for preattack planning were given priority for inventory. Sixty-two ponderosa pine stands and 16 mixed conifer stands were selected.

Sampling Procedure

Once an area was selected, a 3-acre plot was established. Disturbances, topography, and other problems made it necessary to confine the stand sample size to 3 acres. Ninety sample points were established on a 9 by 10 grid systematically arranged over the plot. One square foot was cut in the forest floor down to mineral soil at each point; the sample was then extracted, bagged, and held for analysis. The forest floor consists of the litter (L) layer, recently cast organic material; fermentation (F) layer, material starting to discolor and break down because of weather and microbial action; and the humified (H) layer, where decomposition has advanced. It is the L layer that Brown and Davis (1973) describe as "the loose surface litter on the forest floor, normally consisting of fallen leaves or needles, twigs, bark, cones and small branches that have not yet decayed sufficiently to lose their identity." This surface fuel provides the highly combustible material for flaming combustion and extreme fire behavior during times of high fire danger. The F and H layers make up the combustible ground fuel that lies beneath the loose surface fuel; ground fuel generally burns as glowing combustion. At nine of the sample points, taken on a diagonal across the grid, the L, F, and H layers were collected separately. Woody material ≤ 1 inch in diameter was collected separately also. On 18 of the grid points, heavier woody material was inventoried on 50-foot transects in random directions (Brown 1974). Tree diameters (d.b.h.) were measured on five circular sub-plots of equal area (20% of plot area). Basal area was calculated for each plot from "all trees" and from trees ≥ 5 inches d.b.h. Site index (Minor 1964) was determined from trees having good form and active growth.

Fuel samples were weighed after being oven-dried at 85° to 95° C until weight loss ceased. Rocks and other inorganic material were eliminated from the samples by a combination water bath and muffle furnace combustion process. Woody materials collected were separated into 0- to 1/4-inch- and 1/4- to 1-inch-diameter classes. "Other" material consists

of components such as cones, bark, etc., and pieces of woody and needle material, too small to effectively separate.

Results

Contrary to previous findings by Ffolliott et al. (1968, 1976, 1977) this study did not yield reliable statistical relationships for predicting dead fuel loadings in ponderosa pine and mixed conifer from either basal area or duff depth. Differences between the findings of Ffolliott et al. and this study may be attributable to variations in stand structures, sampling intensity, or in processing the sampled material for weight determination. The results of the study further indicate that a wide range of fuel loading may be expected within and between stands of both ponerosa pine and mixed conifer. For example, the coefficient of variation (the standard deviation divided by the mean) ranged from 46% to 131% in the 62 ponderosa pine stands sampled.

Ponderosa Pine

Basal area in ponderosa pine stands investigated ranged from 55 to 201 square feet per acre. Ponderosa pine stands sometimes included small numbers of juniper, aspen, and oak. Tree size composition (even-aged groups) varied tremendously within each uneven-aged stand studied. Site index (100-year base) varied from 48 to 108.

Needles in the surface fuels (table 1) averaged 1.0 tons per acre and ranged from 0.3 to 2.8 tons per acre. Woody material was not picked up by layer, but a companion study[2] indicates that, on the average, 42%

[2]*Prescribed Burning Interval Study, Study Plan 75.1.5 on file at Forestry Sciences Laboratory, Arizona State University, Tempe, Ariz. 85281.*

Table 1.—Southwestern ponderosa pine dead fuel loadings (basis: 62 stands)

Fuel component	Mean	Standard deviation	Proportion of 0- to 1-inch-diameter dead fuel	Proportion of all dead fuel
	Tons per acre		*Percent*	
L layer (surface fuel) needle material	1.0	0.5	8	5
F layer (ground fuel) needle material	3.8	1.3	30	17
H layer (ground fuel) humus (needle origin)	6.1	2.5	48	28
0- to 1/4-inch-diameter woody material	0.2	.1	2	1
1/4- to 1-inch-diameter woody material	1.0	.5	8	4
Other material	.6	.5	4	3
Total dead fuel 0- to 1-inch diameter	12.7	3.0	100	58

Fuel component	Mean	Standard deviation	Portion of >1-inch-diameter dead fuel	Proportion of all dead fuel
	Tons per acre		*Percent*	
Fuel > 1-inch diameter				
1- to 3-inch material	1.4	0.7	15	6
> 3-inch rotten material	5.0	4.3	54	23
> 3-inch sound material	2.8	4.4	31	13
Total dead fuel >1-inch diameter	9.2	6.1	100	42
All dead fuel	21.9	7.6		100

of the total woody material ≤ 1-inch diameter is found with the surface fuels—39% of the 0- to 1/4-inch material and 44% of 1/4- to 1-inch material. That adds an estimated 0.1 tons of 0- to 1/4-inch material and 0.4 tons of 1/4- to 1-inch material to the needle material, an average of 1.5 tons per acre of surface fuels ≤ 1-inch diameter.

F layer needle material ranged from 0.6 to 6.1 tons per acre with an average of 3.8 tons per acre. Humus layer material, produced primarily from decay of needles, averaged 6.1 tons per acre. A range of humus weights from a low of 1.4 tons per acre to 12.5 tons per acre was found in the 62 study locations. Combining the F and H layer produces a ground fuel loading (needle material) of 9.9 tons per acre. Add to that the woody material ≤ 1-inch diameter, and the figure increases to 10.6 tons per acre.

The 0.6 tons per acre of "other material" found in the study was distributed through the fuel layers. Combining all material ≤ 1-inch diameter lying on the ground, we find an average fuel load of 12.7 tons per acre. Needles obviously made up the biggest portion of fine fuels; about 86% of all material ≤ 1-inch diameter or about 10 tons per acre in mature natural ponderosa pine (data summary in app. 2).

Larger material in the form of fallen snags, limbs, branches, and broken tops add appreciably to the total fuel load. These woody fuels were not sampled, but were estimated on each plot using the planar intersect method (data summary in app. 3). Weight of material 1 to 3 inches in diameter ranged from 0.4 to 3.5 tons per acre. The average was 1.4 tons per acre. Woody material greater than 3 inches in diameter averaged 7.8 tons per acre. The range of weights, however, extended from no large material on one site to 28.8 tons per acre on another. Rotten woody material > 3 inches in diameter accounted for the greatest woody fuel loading (5.0 tons per acre). Sound material of the same size class was somewhat more than half that amount (2.8 tons per acre). Total dead fuels amounted to almost 22 tons per acre of combustible material.

Mixed Conifer

Southwest mixed conifer stands contain varying proportions of Douglas-fir, white fir, southwestern white pine, corkbark fir, ponderosa pine, blue and Engelmann spruce, and aspen. There was a diversity of species composition in the 16 stands selected for study.

Total dead fuel ≤ 1-inch diameter averaged more than 22 tons per acre. Needle material accounted for 78% (17.3 tons per acre), woody material 16.4% (3.6 tons per acre), and other material 5.6% (1.3 tons per acre).

Surface fuel (L layer) in the mixed conifer stands studied was 3.5 tons per acre. Of this, the fine fuels (all except 1/4- to 1-inch woody) amounted to 2.4 tons per acre. Upper level ground fuels (F layer) had a needle fuel loading component much the same as ponderosa pine—3.9 tons per acre. Needle-derived material in the humus (H) layer accounts for 55% of all material ≤ 1 inch (12.3 tons per acre). A summary of the weights are in table 2, complete figures in appendix 4. Material greater than 3 inches diameter averaged 18.6 tons per acre with some stands exceeding 45 tons per acre. Rotten material totaled almost 2 tons per acre more than sound material (data summary in app. 5).

Discussion

Ponderosa Pine

Fuel loadings in "natural," undisturbed ponderosa pine stands are quite heavy. Small particle fuels account for as much of the total loadings as do the large fuels. Although they are not heavy loads, the fact that most of the larger material is rotten may be important. Not only is the rotten material more easily consumed under dry conditions, but it also produces numerous fire brands and provides a more receptive place for fire brands to land and ignite than does sound material.

Mixed Conifer

Fuel loadings in "natural" undisturbed mixed conifer stands are heavy also. Weight of needle material in the L and F layers is comparable to ponderosa pine. However mixed conifer humus is more than twice the weight of that found in ponderosa pine; all size classes of woody material are more than double, also.

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Table 2.—Southwestern mixed conifer dead fuel loadings (basis: 16 stands)

Fuel component	Mean	Standard deviation	Proportion of layer	Proportion of 0- to 1-inch-diameter dead fuel	Proportion of all dead fuel
	----Tons per acre----		--------------Percent--------------		
L layer (surface fuel)					
Needle material	1.1	0.5	30	5	2
0- to 1/4-inch woody material	0.7	.3	21	3	2
1/4- to 1-inch woody material	1.3	.7	36	6	3
Other material	.4	.3	13	2	1
Total	3.5	1.1	100	16	8
F layer (ground fuel)					
Needle material	3.9	1.6	79	17	8
0- to 1/4-inch woody material	0.3	0.1	7	1	1
1/4- to 1-inch woody material	.4	.2	7	2	1
Other material	.4	.2	7	2	1
Total	5.0	1.8	100	22	11
H layer (ground fuel)					
Humus (needle origin)	12.3	4.7	90	56	28
0- to 1/4-inch woody material	0.4	0.4	3	2	1
1/4- to 1-inch woody material	.6	.5	4	2	1
Other material	.4	.5	3	2	1
Total	13.7	5.6	100	62	31
Total dead fuel 0- to 1-inch diameter	22.2	6.2			

Fuel component	Mean	Standard deviation	Proportion of >1-inch-diameter dead fuel	Proportion of all dead fuel
	----Tons per acre----		--------Percent--------	
Fuel > 1-inch diameter				
1- to 3-inch material	3.3	1.3	15	8
> 3-inch rotten material	10.3	7.8	47	23
> 3-inch sound material	8.3	7.2	38	19
Total dead fuel >1-inch-diameter	21.9	13.7	100	50
All dead fuel	44.1	18.0		100

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Appendix 1

Common and Scientific Names of Trees

Aspen	*Populus* spp.
Blue spruce	*Picea pungens* Engelm.
Corkbark fir	*Abies arizonica* (Merriam) Lemm.
Douglas-fir, Rocky Mountain	*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco
Eastern white pine	*Pinus strobus* L.
Engelmann spruce	*Picea engelmannii* Parry
Jack pine	*Pinus banksiana* Lamb.
Juniper	*Juniperus* spp.
Loblolly pine	*Pinus taeda* L.
Longleaf pine	*Pinus palustris* Mill.
Oak	*Quercus* spp.
Ponderosa pine	*Pinus ponderosa* Laws.
Quaking aspen	*Populus tremuloides* Michx.
Red pine	*Pinus resinosa* Ait.
Slash pine	*Pinus caribaea* Morelet
Southwestern white pine	*Pinus strobiformis* Engelm.
White fir	*Abies concolor* (Gord. & Glend.) Hildebr.

Appendix 2

Dead fuel loading (tons per acre) in southwestern ponderosa pine stands (≤ 1-inch-diameter material)

	Needle material			Other material[1]	Woody material		Dead fuel 0- to 1-inch diameter
	L layer	F layer	H layer		0 to 1/4 inch	1/4 to 1 inch	
Kaibab NF							
Jacob Lake	1.8	4.5	8.8	1.4	0.4	0.2	17.1
Lambs Lake	0.8	6.1	5.2	0.5	.2	1.0	13.8
Lupine	.8	1.3	8.9	.9	.2	1.4	13.5
Three Lakes	.9	2.3	11.9	1.4	.1	1.1	17.7
Grand Canyon National Park							
Big Taper	.4	6.0	4.5	1.1	.1	1.2	13.3
Cape Royal	1.0	4.7	9.8	.8	.3	1.4	18.0
Naji Point	1.6	3.7	12.5	.7	.2	1.7	20.4
Walhalla	.6	6.7	8.7	1.3	.2	.8	18.3
Coconino NF							
Clints Well	.9	3.3	11.7	.6	.2	1.0	17.7
Fort Valley	1.1	4.7	7.9	1.4	.2	.1	15.4
G.A. Pearson Natural Area	.8	2.2	9.5	.3	.2	1.0	14.0
Long Valley	1.5	3.1	5.8	.4	.4	.5	11.7
Tonto NF							
Ellison Creek	—	—	—	—	—	—	4.8
Tonto Village	—	—	—	—	—	—	8.2
Apache-Sitgreaves NF							
Agate	.9	2.3	7.7	.2	.1	.3	11.5
Bear Rock	—	—	—	—	—	—	12.7
Blue Range Primative Area	1.0	2.6	4.1	.4	.3	1.9	10.3
Bull Flat	.9	2.5	2.4	.5	.3	1.8	8.4
Castle Creek, South	1.4	3.2	5.4	0.3	0.4	1.6	12.3
Fawn	0.8	4.1	7.7	.3	.1	.7	13.7
Hawk-Owl	1.2	3.0	9.0	1.0	.3	1.0	15.5
Holcomb Sale	.6	3.0	4.1	.4	.2	1.5	9.8
Horsefly	1.5	4.5	7.5	.5	.2	1.0	15.2
Larson Ridge	.8	3.1	2.6	.3	.6	2.2	9.6
Mamie Creek	.9	4.4	4.5	.1	.1	.5	10.5
Red Hill Trail	.7	1.8	4.9	.1	.1	.7	8.3
Watts Sale	1.6	4.4	5.2	.3	.1	.7	12.3
Wildcat Road	.5	1.8	3.0	1.1	.2	2.1	8.7
San Carlos Apache Indian Reservation							
Bronco Junction	—	—	—	—	—	—	12.3
Turkey Tank	—	—	—	—	—	—	14.9
Wallow	1.4	4.8	9.0	.4	.1	.4	16.1
Fort Apache Indian Reservation							
Bonito Creek	2.8	4.9	6.6	.3	.1	.5	15.2
Lofer Ridge	1.2	5.8	6.0	.6	.3	1.0	14.9
Gila NF							
High Clark Springs	.7	1.9	9.2	.5	.1	.6	13.0
Meadow Creek	1.0	3.8	4.5	.1	.3	.4	10.1
Meason Park	—	—	—	—	—	—	9.7
Multiple Use Demo. Area	.7	5.1	4.1	.2	.2	.6	10.9
Pine Flat	.9	3.2	5.9	.1	.1	.2	10.4
School Marm	.7	3.6	6.5	.6	.1	1.2	12.7
Sheep Corral Canyon	.8	5.8	4.6	.3	.1	.5	12.1
Sheep Springs	.8	5.3	2.1	.1	.3	.8	9.4
State Line	1.9	2.9	1.4	1.8	.7	2.7	11.4
Trap Springs	.8	3.8	5.9	.2	.2	.9	11.8
Navajo Indian Reservation							
Wheatfields	.6	4.1	3.3	.7	.1	.6	9.4
Cibola NF							
Boon Place	.8	4.3	3.4	.1	.3	.7	9.6
Fubar	.6	.6	5.4	.1	.2	.4	7.3
Upper Section	.5	4.1	3.6	.4	.1	.7	9.4

Appendix 2 — Continued

	Needle material				Woody material		Dead fuel
	L layer	F layer	H layer	Other material[1]	0 to ¼ inch	¼ to 1 inch	0 to 1-inch diameter
Santa Fe NF							
Cat Mesa	1.5	4.4	6.6	.5	.2	.9	14.1
Firewood	1.0	3.3	7.9	.6	.3	1.1	14.2
Mesa Junction	.6	2.5	5.0	2.4	.1	.6	11.2
Carson NF							
El Valle	1.5	2.9	6.1	.4	.3	1.1	12.3
Kiowa Mountain	.8	5.7	8.3	1.0	.1	.6	16.5
Ojitos	.7	3.8	7.4	.1	,1	.8	12.9
Rio Trampas	.7	5.6	3.3	.5	.1	1.2	11.4
Bandelier National Monument							
Escobas Mesa	1.6	3.1	5.2	.5	.5	.7	11.6
Lincoln NF							
Daisy	1.4	4.5	6.5	.9	.5	1.3	15.1
Hughes Canyon	1.3	3.5	5.8	.7	.5	.8	12.6
San Juan NF							
First Fork	1.0	4.0	5.8	1.3	.6	1.7	14.4
Little Devil Creek	.3	2.3	5.0	.6	.4	1.2	9.8
Mud Spring	.5	3.2	5.7	.4	.3	.5	10.6
Piedra Trail	.4	3.3	6.0	.4	.3	.6	11.0
Rocky Draw	.7	6.1	5.0	.4	.5	1.2	13.9
Study average (N=56/62)	1.0	3.8	6.1	.6	.2	1.0	12.5

[1]Other material: includes cones, bark, miscellaneous plant parts, and any other material too small to separate effectively.

Appendix 3

Dead fuel loading (tons per acre) in southwestern ponderosa pine stands (>1-inch-diameter material)

	1 to 3 inches	Over 3-inch sound	Over 3-inch rotten	Total over 3 inches	Total 1 to over 3 inches	Total[1] dead fuel
Kaibab NF						
Jacob Lake	2.0	2.8	3.7	6.5	8.5	25.6
Lambs Lake	2.0	0..8	3.8	4.6	6.6	20.5
Lupine	2.3	2.8	5.3	8.1	10.4	23.9
Three Lakes	2.0	4.2	2.7	6.9	8.9	26.6
Grand Canyon National Park						
Big Taper	0.8	3.1	0.6	3.7	4.5	17.9
Cape Royal	.9	5.2	1.1	6.3	7.2	25.1
Naji Point	1.8	2.6	4.5	7.1	8.9	29.3
Walhalla	.5	1.3	.0	1.3	1.8	20.2
Coconino NF						
Clints Well	1.4	10.4	18.4	28.8	30.2	47.9
Fort Valley	.8	.9	11.8	12.7	13.5	28.9
G. A. Pearson Natural Area	.4	7.9	5.4	13.3	13.7	27.7
Long Valley	1.2	3.1	17.4	20.5	21.7	33.4
Tonto NF						
Ellison Creek	1.0	.7	1.9	2.6	3.6	8.4
Tonto Village	.5	.2	1.1	1.3	1.8	10.0
Apache-Sitgreaves NF						
Agate	1.7	.6	4.2	4.8	6.5	18.0
Bear Rock	2.7	2.6	6.6	9.2	11.9	24.6
Blue Range Primitive Area	1.1	6.1	4.2	10.3	11.4	21.7
Bull Flat	1.4	3.3	4.6	7.9	9.3	17.8
Castle Creek, South	1.9	2.8	14.9	17.7	19.6	31.9
Fawn	2.7	1.4	3.6	5.0	7.7	21.4
Hawk-Owl	1.9	2.5	9.3	11.8	13.7	29.1
Holcomb Sale	1.1	1.6	9.1	10.7	11.8	21.6

Appendix 3.—Continued

	1 to 3 inches	Over 3-inch sound	Over 3-inch rotten	Total over 3 inches	Total to over 3 inches	Total dead fuel
Horsefly	2.0	13.1	3.4	16.5	18.5	33.8
Larson Ridge	2.5	3.8	9.4	13.2	15.7	25.2
Mamie Creek	0.9	1.6	3.4	5.0	5.9	16.4
Red Hill Trail	.8	0.4	7.2	7.6	8.4	16.7
Watts Sale	.6	.7	1.5	2.2	2.8	15.1
Wildcat Road	1.3	.2	12.6	12.8	14.1	22.8
San Carlos Apache Indian Reservation						
Bronco Junction	1.1	.2	1.8	2.0	3.1	15.4
Turkey Tank	1.5	4.4	7.2	11.6	13.1	28.0
Wallow	1.4	1.2	6.5	7.7	9.1	25.2
Fort Apache Indian Reservation						
Bonito Creek	2.0	8.6	4.5	13.1	15.1	30.3
Lofer Ridge	3.5	17.4	4.9	22.3	25.8	40.7
Gila NF						
High Clark Springs	1.3	.6	10.7	11.3	12.6	25.6
Meadow Creek	.7	.0	.0	.0	0.7	10.8
Meason Park	.7	2.2	2.1	4.3	5.0	14.7
Multiple Use Demonstration Area	2.5	1.1	1.6	2.7	5.2	16.1
Pine Flat	.7	.1	.9	1.0	1.7	12.1
School Marm	2.5	1.1	8.4	9.5	12.0	24.6
Sheep Corral Canyon	1.0	3.6	13.9	17.5	18.5	30.6
Sheep Springs	.8	1.1	.0	1.1	1.9	11.2
State Line	1.3	.1	4.9	5.0	6.3	17.8
Trap Springs	2.3	.0	6.8	6.8	9.1	20.8
Navajo Indian Reservation						
Wheatfields	.4	.4	4.1	4.5	4.9	14.3
Cibola NF						
Boon Place	.6	1.1	9.6	10.7	11.3	20.9
Fubar	.8	2.4	3.0	5.4	6.2	13.4
Upper Section	.4	.6	8.0	8.6	9.0	18.4
Santa Fe NF						
Cat Mesa	1.3	6.2	8.1	14.3	15.6	29.6
Firewood	.7	13.0	2.6	15.6	16.3	30.5
Mesa Junction	1.8	2.1	7.9	10.0	11.8	23.1
Carson NF						
El Valle	.4	.0	.5	.5	.9	13.1
Kiowa Mountain	.8	4.7	2.1	6.8	7.6	24.1
Ojitos	.9	.9	3.1	4.0	4.9	17.8
Rio Trampas	1.4	.4	1.8	2.2	3.6	15.0
Bandelier National Monument						
Escobas Mesa	.6	1.7	.7	2.4	3.0	14.5
Lincoln NF						
Daisy	2.1	2.4	3.0	5.4	7.5	22.5
Hughes Canyon	1.4	2.6	2.7	5.3	6.7	19.3
San Juan NF						
First Fork	1.3	3.0	2.9	5.9	7.2	21.6
Little Devil Creek	2.0	.6	1.8	2.4	4.4	14.1
Mud Spring	2.0	1.3	1.6	2.9	4.9	15.4
Piedra Trail	.6	1.5	1.9	3.4	4.0	15.0
Rocky Draw	.7	1.8	.9	2.7	3.4	17.3
Study average	1.4	2.8	5.0	7.9	9.2	21.7

[1]Total dead fuel is summation of total 1- to 3-inch material and dead fuel (0- to 1-inch diameter), appendix 2.

Appendix 4

Dead fuel loading (tons per acre) in southwestern mixed conifer stands
(≤ 1-inch diameter material)

	Needle material				Woody material		Dead fuel
	L layer	F layer	H layer	Other material[1]	0 to 1/4 inch	1/4 to 1 inch	0- to 1-inch diameter
Apache-Sitgreaves NF							
Butterfly Spring	1.3	3.1	17.1	1.6	1.7	4.7	29.5
Canker	1.3	5.7	11.2	0.6	1.6	1.8	22.2
Double Cienega	0.6	2.9	16.0	2.9	1.9	4.1	28.4
Dump	2.0	4.0	12.2	1.0	1.8	1.9	22.9
Fire Scar	1.5	3.1	12.2	.6	1.1	2.3	20.8
Hannigan	1.0	2.1	19.9	1.2	2.8	3.8	30.8
HQ Cienega	1.2	4.5	12.3	.3	1.1	1.9	21.3
Terry Flats	.6	4.5	17.8	1.1	2.3	2.7	29.0
Willow Creek	1.0	7.0	17.1	2.1	1.4	2.1	30.7
Bandelier National Monument							
Frijoles	1.1	3.3	9.8	1.5	1.0	2.0	18.7
Carson NF							
Cunningham Sale	.8	2.0	15.3	2.1	0.8	1.7	22.7
Maquinita Sale	.8	7.1	10.1	.9	.8	1.2	20.9
Palo Pass	.4	2.9	9.3	1.1	1.1	1.6	16.4
Lincoln NF							
Cloudcroft	1.0	3.3	4.3	.8	1.3	0.9	11.6
Silver Saddle	.5	2.0	9.2	1.1	1.1	1.3	15.2
Santa Fe NF							
Calaveras	1.9	4.8	3.7	.9	1.3	1.0	13.6
Study average (N=16)	1.1	3.9	12.3	1.3	1.4	2.2	22.2

[1]Other material: includes cones, bark, miscellaneous plant parts, and any other material too small to separate effectively.

Appendix 5

Dead fuel loading (tons per acre) in southwestern mixed conifer stands
(> 1-inch-diameter material)

	1 to 3 inches	Over 3 inches sound	Over 3 inches rotten	Total over 3 inches	Total 1 to over 3 inches	Total[1] dead fuel
Apache-Sitgreaves NF						
Butterfly Spring	4.1	23.4	22.9	46.3	50.4	79.8
Canker	1.9	2.5	12.3	14.8	16.7	38.8
Double Cienega	4.8	8.7	10.9	19.6	24.4	52.8
Dump	4.8	9.7	5.0	14.7	19.5	42.4
Fire Scar	5.0	2.9	2.5	5.4	10.4	31.2
Hannigan	3.9	11.5	13.7	25.2	29.1	59.9
HQ Cienega	1.5	6.2	8.5	14.7	16.2	37.5
Terry Flats	3.9	23.6	30.9	54.5	58.4	87.5
Willow Creek	2.5	2.2	13.6	15.8	18.3	48.9
Bandelier National Monument						
Frijoles	2.4	1.6	9.6	11.2	13.6	32.3
Carson NF						
Cunningham Sale	3.6	5.2	7.1	12.3	15.9	38.6
Maquinita Sale	2.3	4.0	3.3	7.3	9.6	30.5
Palo Pass	5.0	3.1	7.6	10.7	15.7	32.1
Lincoln NF						
Cloudcroft	2.1	5.4	12.5	17.9	20.0	31.6
Silver Saddle	1.5	17.8	1.6	19.4	20.9	36.1
Santa Fe NF						
Calaveras	3.1	5.7	2.6	8.3	11.4	25.0
Study average	3.3	8.3	10.3	18.6	21.9	44.1

[1]Total dead fuel is summation of total 1- to 3-inch material and dead fuel (0- to 1-inch diameter), appendix 2.

Sackett, Stephen S. 1979. Natural fuel loadings in ponderosa pine and mixed conifer forests of the Southwest. USDA For. Serv. Res. Pap. RM-213, 10 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Natural dead fuel loading in 62 undisturbed southwestern ponderosa pine stands averaged 21.9 tons per acre, 12.7 tons per acre ≤1-inch diameter. Sixteen mixed conifer stands averaged 44.1 tons per acre of dead fuel. Heavy humus loads contributed to loading of 22.2 tons per acre of fuel ≤1-inch diameter.

Keywords: Fuel loading, *Pinus ponderosa*, natural fuels, litter, woody fuels, duff, fuel management

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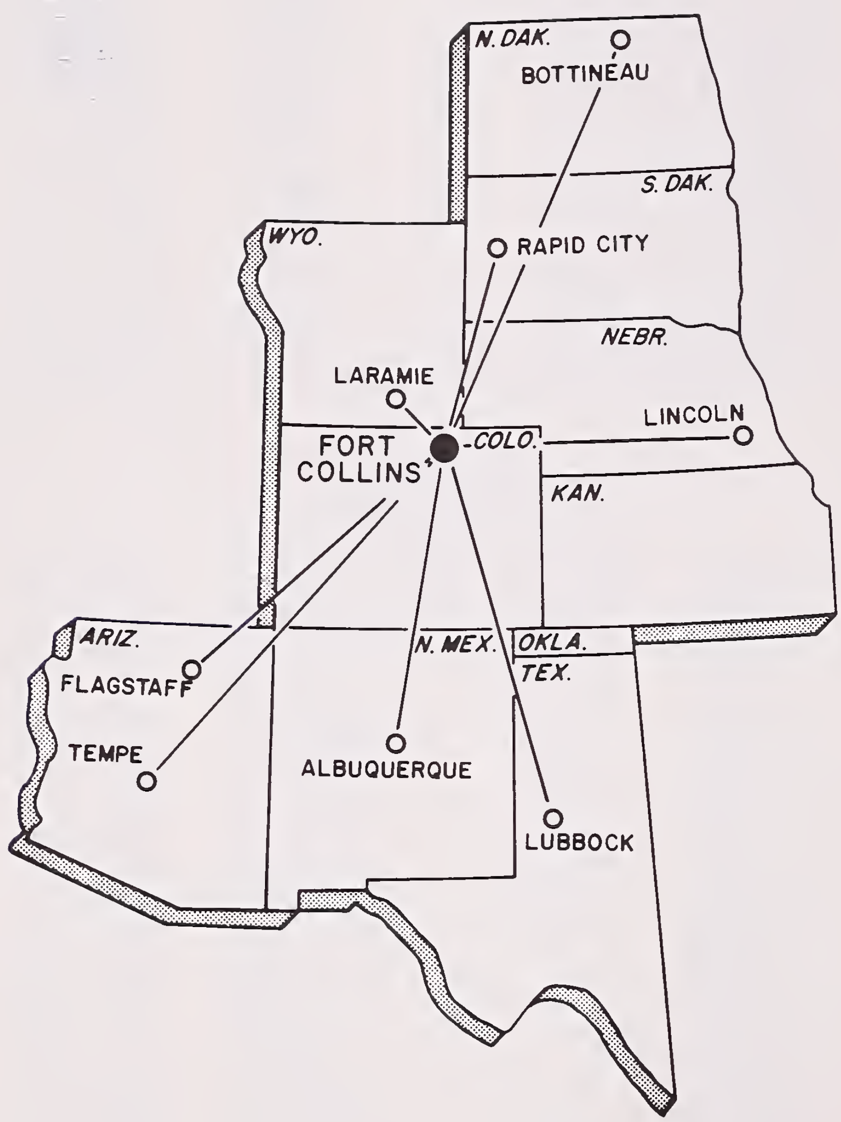
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